Wetland Vegetation, Environmental Factors, and Their Interaction in Strip Mine Ponds, Stockdams, and Natural Wetlands

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Abstract

Water regime, chemical features, temperature factors, light penetration, substrate properties, and physical characteristics are described for Northern Great Plains strip mine ponds and stockdams, followed by a discussion of how their interaction determines wetland plant community composition and resulting wildlife habitat quality for consumptive and nonconsumptive resource utilization.

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Management Implications

Thousands of impoundments in the form of coal strip mine ponds, stockdams (stockponds formed by damming natural drainages), and dugouts (stockponds formed by excavating large pits) have been constructed where natural wetlands are largely absent in the unglaciated areas of the Northern Great Plains. These specialized ecosystems can be managed to provide natural resource consumers with values similar to those provided by natural wetlands of the prairie pothole region. However, land management plans are needed if these constructed impoundments are to improve wildlife habitat, fishery habitat, irrigation, water sources for livestock, and recreational activities.

The associated wetland plant communities on these constructed impoundments should be a major concern in developing management plans since this ecosystem component supports a variety of wildlife species through the habitat it provides, particularly for waterfowl. Escape cover, nesting cover, brood rearing cover, and food sources (both vegetative and faunistic), all required by waterfowl, are found in wetland plant communities. In addition, recreational activities such as bird-watching, wildlife photography, hunting, trapping, fishing, and aesthetic endeavors are enhanced by the presence of diversified, well-developed wetland plant communities.

Existing strip mine ponds on the Northern Great Plains commonly are characterized by precipitous shorelines, few shallow areas, steep spoil piles, and heavy erosion. Most of these impoundments, especially the most recently mined, exhibit sparse growth of wetland vegetation and contribute little to the availability of wildlife habitat. On the other hand, stockdams with gently sloping shorelines, many shallow areas, and little erosion generally display lush, well-developed wetland vegetation zones except where heavy livestock use prevails. Heavy livestock use around stockdams tends to disrupt wetland vegetation and reduce the quality of wildlife habitat through grazing activity, trampling, and increasing erosion and sediment loads into the wetland basin. Management plans for these constructed impoundments could alleviate major problems and enhance wetland vegetation for both consumptive and non-consumptive resource utilization.

The development of wetland vegetation in Northern Great Plains impoundments is governed by a host of complex, interacting environmental variables such as water regime, water chemical features, water temperature factors, light penetration, submerged substrate properties, and basin physical characteristics. The nature and presence of specific plant species reflect current environmental conditions of the aquatic ecosystem, resulting from the interaction of previously described environmental variables.

Before resource managers can develop management plans that will maximize multiple uses on these constructed impoundments, ecological relationships between biological, chemical, and physical factors must be well understood. A logical approach toward developing management plans is to determine the major environmental factors operating on wetland plant community expression, try manipulating these factors using a variety of techniques learned from future research, and incorporate those techniques which best produce the desired expression of wetland vegetation into the final management plan.

Herein lies the challenge for resource managers. We must first pool all the available information on the ecology of constructed impoundments, and then concentrate future research efforts on identifying influential environmental factors and the responses from manipulation techniques that optimize wildlife habitat value.

Our knowledge about the ecology of aquatic ecosystems on constructed impoundments is extremely limited as evidenced by a lack of publications dealing with ecological relationships on livestock ponds and only sparse information about wetland vegetation on strip mine ponds. Most of the information available for strip mine ponds deals with reclamation of terrestrial vegetation.

The implications of developing management plans for these constructed impoundments are far reaching, especially in light of rapid, future development of energy sources. As energy development continues, more habitat for wildlife will be disrupted or destroyed, more public land for consumptive and nonconsumptive resource uses will be closed or reduced in area, and new, potentially valuable wetland basins will emerge. Resource managers must be prepared to intensively manage these new habitat parcels to optimize multiple use value and restore habitat value in previously disturbed impoundments.

Introduction

Constructed impoundments are becoming more numerous in the Northern Great Plains each year. Coal strip mine ponds—formed when surface mine pits fill with underground water, precipitation, and runoff—are becoming more prevalent in North Dakota, South Dakota, Wyoming, and Montana as the demand for energy increases. During 1966, approximately 53.8 quadrillion Btu's of energy were consumed in the United States. By the year 2000, an estimated 159 quadrillion Btu's will be required annually. Demand for coal as an energy source is estimated to be 53% greater in 1980 compared with 1967, and will be 78% greater in the year 2000 compared with 1980 (Bureau of Mines 1971).

Lignite coal, the predominate type in North and South Dakota and sub-bituminous coal, the predominate type in Wyoming and Montana, are used mainly for generating electric power. Large reserves of these coals in the Northern Great Plains make strip mining methods profitable. Averitt (1973) estimated total coal reserves (with an overburden of 0-915 m) of North Dakota at 317.9 billion metric tons (all lignite); South Dakota, 1.8 billion metric tons (all lignite); Wyoming, 109.4 billion metric tons (11.5 bituminous, 97.9 sub-bituminous); and Montana, 201.1 billion metric tons (2.1 bituminous, 119.5 sub-bituminous, and 79.5 lignite). These totals represent 57% and 98% of all sub-bituminous and lignite reserves in the United States respectively. As of January 1, 1976, total lignite mined in North Dakota by stripping methods was 156.9 million metric tons or 1% of the total strippable resource (Bluemle 1977). As more rangeland water impoundments emerge from intensified future strip mining activity, the demand for more intensive management plans on these ecosystems will increase.

Other types of constructed water impoundments becoming increasingly numerous are stockdams and dugouts. Approximately 220,000 stockdams and 40,000 dugouts were constructed in North Dakota, South Dakota, eastern Wyoming, and eastern Montana by 1964 (Bue et al. 1964) . These figures represent estimates from U.S. Department of Agriculture records for impoundments constructed with federal assistance and by private landowners. Since 1964, the number of these impoundments on the Northern Great Plains has probably doubled. Although the exact number of stockdams and dugouts is not known, they contribute to the diversity of rangeland ecosystems.

Associated wetland plant communities, common to all three constructed impoundments, are one of the more important components of these ecosystems. These plant communities provide habitat to a variety of fauna for both consumptive and non-consumptive resource use.

Most research involving wetland plant communities has focused primarily on natural wetlands of the prairie pothole region. Little research has been conducted on wetland vegetation of coal strip mine ponds, stockdams, and dugouts. A large amount of information is available concerning reclamation of strip mines in the eastern United States. However, most of this information focuses on reclamation of terrestrial vegetation on strip mine spoil banks with little or no emphasis on the wetland vegetation in strip mine ponds. Wetland vegetation analyses of strip mine ponds, stockdams, and dugouts in the Northern Great Plains are not available. There is a great need for research on the taxonomy, ecology, and biology of wetland plant communities associated with these constructed water impoundments (Kadlec and Wentz 1974).

Objectives

The purpose of this paper is to consolidate current information on the ecology of wetland vegetation and associated environmental factors from strip mine ponds, stockdams, and dugouts with supplemental information on natural wetlands. This reference is a preliminary source to assist researchers, educators, and resource managers prior to full-scale investigations of wetland vegetation on Northern Great Plains strip mine ponds, stockdams, or dugouts.

This paper describes (1) the need to develop more intensified management plans for strip mine ponds, stockdams, and dugouts, especially in light of increased future strip mining activity, (2) the formation and physical characteristics of these diversified rangeland ecosystems, (3) the history of wetland vegetation studies, (4) major environmental factors functioning on constructed impoundments, and (5) the interaction between environmental factors and wetland plant communities.

Physical Characteristics of Constructed Impoundments

Strip mine ponds originate from open-pit mining where soil overburden is removed by power shovels, draglines, and tractor-drawn scoops to reach coal seams situated at shallow depths below the soil surface. In earlier mining processes, overburden was deposited in long ridges (ridge height varying with overburden thickness) parallel to the exposed cut as coal removal continued at right angles to the spoil piles. Long, narrow valleys 3-8 m deep were formed between ridges of spoil material. The final cut, with overburden and coal removed, often filled with water, forming a lake or pond surrounded by steep, high banks (fig. 1) (Crawford 1942, Riley 1954, Brewer and Triner 1956). Overburden removal buried nontoxic surface materials underneath the spoil pile and exposed toxic acid material from soil layers directly above the coal seam. Oxidation of these toxic materials and subsequent runoff from spoil piles resulted in sulfuric acid accumulation in the impoundment, causing the problems associated with older strip mining methods (fig. 2) (Riley 1960).

Figure 1.—Precipitous shorelines, few shallow areas, restricted water-level fluctuations, and steep spoil piles with extensive bare exposures, a result of early strip mining activity, are major factors limiting development of wetland vegetation on these constructed impoundments. Water from underground aquifers filled the abandoned open-pit mine forming a strip mine pond.

Figure 2.—Oxidation of toxic sub-surface spoil material from surrounding spoil banks, combined with subsequent runoff and erosion, directly determine the chemical composition of basin water. Acting as storage reservoirs for toxic pollutants carried in runoff, the aquatic habitat of these impoundments often retard wetland plant development.

The increased strip mining activity in recent years on the Northern Great Plains, has prompted more stringent federal laws controlling surface mining reclamation. Within these federal guidelines, individual states have adopted their own regulations regarding surface mining reclamation. In many cases state laws are more stringent than the guidelines established by the federal government.

In North Dakota, surface coal mining operators are required to match the surrounding topography in reclamation efforts and "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining." The creation of any permanent water impoundment must be approved by state regulatory agencies through detailed mining and reclamation plans before mining permits are issued. Planned water impoundments must meet specific standards determined by state engineers.[2]

In Wyoming, the final exposed mining pit and surrounding spoil material must be "sloped, graded, and contoured so as to blend in with the topography of the surrounding terrain and provide for access and revegetation." Steep, parallel ridges of spoil material are not allowed under today's stricter reclamation laws (Department of Environmental Quality 1978). Montana and South Dakota have similarly strict reclamation laws governing the final appearance of strip mined areas.

Most older strip mine ponds are characterized by precipitous shorelines, absence of shallow areas, and presence of steep spoil piles with extensive bare exposures limiting the production of vegetation and fish. Such ponds vary from less than 1 ha to several hectares in surface area with a long, narrow configuration to the basin (Lewis and Peters 1955, Davis 1971, Coe and Schmelz 1972).

Bell (1956) found that in southern Illinois, intensive erosion of the 40-60° soil slopes produced a narrow, mucky shelf around the pond perimeter. Burner and Leist (1953) reported that in Kansas, older spoil piles have rounded ridges caused by erosion and crumbling of spoil material.

Working in Missouri, Parsons (1964) classified strip mine ponds into two types based on continuity of the water mass and shoreline length. One type, called "chevron" ponds, were characterized by having 90-95% uninterrupted water areas (linkages between ponds flooded) with extensive shoreline length, compared to surface area. A second type, called "parallel" ponds, had 50% or less uninterrupted water area (linkages between ponds interrupted with land mass) with restricted shoreline length, compared to surface area. Riley (1960) found strip mine ponds in Ohio with water depths less than 7.5 m, and with underground springs and runoff as the principle water supplies.

Stockdams in the Northern Great Plains are formed by constructing dams (earthen or concrete) across natural drainage routes, forcing water to accumulate and form an impoundment. Dugouts, in contrast to stockdams, are large excavated holes designed to catch runoff or intercept ground water. Spoil from dugouts is placed parallel along the sides of the excavated hole. Both stockdams and dugouts are constructed primarily to provide water for livestock, although other benefits such as wildlife habitat accrue (Bue et al. 1964).

Stockdams on the Northern Great Plains are wetland basins having gently sloping shorelines except at the dam, having surface areas from less than 1 to 16 ha, containing maximum depths of less than 1-6 m, and with runoff as the principal water source (fig. 3) (Bue et al. 1964). Bue et al. (1964) noted that aquatic vegetation will appear during the second year on a newly constructed pond and become established in 3-5 years.

Strip mine ponds, stockdams, and artificial wetlands can be considered "wetlands" according to a broad definition which refers to any lowland area containing water, and ranging from basins or flats which undergo seasonal submergence to lands which are waterlogged or flooded at all times (Martin et al. 1953, Shaw and Fredine 1956, Cowardin et al. 1979). The term wetlands encompasses marshes, swamps, potholes, sloughs, ponds, and shallow lakes.

Some strip mine ponds and stockdams probably possess a potentially longer lifetime than that of natural wetlands, because the artificial ponds have greater water depths, a more permanent water table, and larger watershed areas (Golet and Larson 1974). Dineen (1953), in a study of a Minnesota pond, found that annual deposition of organic matter from emergent plants was a major factor in reducing the area and depth of small ponds.

History of Wetland Vegetation Studies

Early studies of aquatic macrophytes, largely conducted in north-central United States, were primarily descriptive, with their authors emphasizing the floristic composition (Stout 1913, Pearsall 1920, Denniston 1921, Rickett 1921, 1924, Butcher 1933, Thomson 1944, Love and Love 1954). These studies usually included some environmental effects on wetland vegetation and were forerunners of more ecologically-oriented floristic investigations such as Graham and Henry (1933), Wilson (1937), Misra (1938), Potzger and Van Engel (1942), Swindale and Curtis (1957), Mandossian and McIntosh (1960), Modlin (1970), and Zutshi (1975).

Wetland plant studies evolved into complex investigations directed at the "ecosystem." More recent ecological investigations of wetland vegetation attempt to define environmental-edaphic-vegetation relationships using a variety of statistical analyses, including simple correlation techniques, gradient analysis, and principal components analysis (Walker and Coupland 1968, Van der Valk and Bliss 1971, Walker and Wehrhahn 1971, Dirschl and Coupland 1972, Auclair et al. 1973, 1976a, 1976b and Kologiski 1977).

[2]*North Dakota Surface Mine Reclamation Act. 1979. Environmental protection performance standards, chapter 38-14.1-14.7, North Dakota Century Code, Bismarck, N. D. Draft proposal.*

Figure 3.—Stockdams, formed by constructing dams across natural drainage routes, support more extensive wetland vegetation development due to gently sloping shorelines and absence of disturbed surface soil material.

Information available on strip mine ponds and associated wetland vegetation frequently is part of a more inclusive limnological investigation (Burner and Leist 1953, Lewis and Peters 1955, Simpson 1961, Parsons 1964, Tobaben 1969, Campbell and Lind 1969, Davis 1971, Coe and Schmelz 1972). However, Bell (1956) in Illinois, Dinsmore (1958) in Pennsylvania, and Riley (1960) in Ohio focused primarily on the ecology of wetland vegetation in strip mine waters. Less information is available on the ecology of wetland vegetation in stockdams and artificially created wetlands than on strip mine ponds. Dane (1959) and Lathwell et al. (1969) have conducted ecological investigations on artificially created marshes in New York.

There is considerably more literature addressing the ecology of wetland vegetation on natural wetlands of the prairie pothole region. Occasionally this literature is cited in this report to supplement the lack of available information on strip mine ponds and stockdams in order to provide the reader with an example of ecological relationships on constructed impoundments.

Environmental Factors Functioning on Constructed Impoundments

Ecological studies of wetland vegetation cannot be restricted to vegetational aspects alone, but must include various environmental factors which interact to produce the expression of wetland plant community structure. An understanding of how environmental factors function, their interaction, and their relationship to wetland vegetation is necessary before management plans can be formulated.

Water Regime

Seasonal water levels fluctuates to some degree in all wetland basins through inflow and outflow pathways. These fluctuations can be beneficial to wetland plant establishment, provided the magnitude of fluctuation is not excessive. Moderate fluctuation provide optimum moisture conditions suitable to a wider diversity of wetland vegetation. Studying Illinois strip mine ponds, Bell (1956) found extreme fluctuations in water level caused by unmoderated overflow from steep basin slopes, lateral movement of subsurface water away from the pond through surrounding porous spoil materials, and restricted size of the watershed. Rapidly changing water levels on steep sloped strip mine ponds produce quick, extreme changes in moisture conditions to which many wetland plants are unable to adapt. As a result, plant species composition and density is limited.

No information is available on the magnitude of water level fluctuations in stockdams and its effects on wetland vegetation establishment. More research is needed in this area before development of management plans for these ecosystems.

However, considerable work on the hydrology of natural wetlands indicates that the water budget on these ecosystems involves gains from inflow and losses from outflow (Eisenlohr 1965, 1966, 1967, 1969a, 1969b, 1969c, 1972, Eisenlohr and Sloan 1968, Shjeflo 1968, Sloan 1970, 1972). The magnitude of water level fluctuations from inflow and outflow water budgets on natural wetlands, in terms of water depth in wetland plant communities, is minimized by characteristic shallow basins. As a result, a greater variety of wetland plant species can tolerate the more favorable moisture regime.

Major sources of water inflow into wetland basins are through direct precipitation, surface runoff from the surrounding watershed, and seepage inflow from ground water tables. The amount of water entering a wetland in spring is determined by the amount of snow accumulation in the watershed, intensity of snowmelt caused by prevailing air temperatures, level of soil moisture at freeze-up, and depth of frost penetration in the soil during the preceeding fall (Millar 1969b, Daborn 1976).

Water outflow is primarily by evaporation from the water surface, evapotranspiration from marginal vegetation, seepage outflow from the pond bottom, and overflow around pond margins.

Presence of extensive marginal emergent vegetation complicates the water regime of a wetland by both (1) reducing water loss from evaporation by sheltering the water surface from wind and radiation and (2) increasing water loss through evapotranspiration (Eisenlohr 1965, 1969a). Eisenlohr (1965) found that plant evapotranspiration rates at the beginning and end of a growing season were less than evaporative loss from the free water surface. However, total evapotranspiration loss for the entire growing season on a prairie pothole filled with vegetation may be greater than the evaporation rate if no vegetation were present.

In dry years when evapotranspiration is higher, water loss from a wetland filled with vegetation may be excessive enough to deplete moisture conditions required by wet meadow plant communities located on the outer fringes of the wetland basin. In this situation, wetland plant composition may change resulting in decreased waterfowl nesting and feeding areas. To minimize water loss from a wetland basin through evaportation or evapotranspiration, wetlands completely filled with vegetation should be opened by blasting or other mechanical means to decrease water lost through evapotranspiration. On sparsely vegetated wetlands, management practices such as contouring basin slopes and water level control should be considered as a means to encourage wetland plant development along basin margins to decrease water loss by evaporation. Again, more research is needed on water loss in constructed impoundments so management plans can be developed from sound field information.

Likewise, removal of peripheral vegetation through cultivation or grazing may reduce spring runoff into the wetland by reducing the amount of accumulated snow "trapped" by vegetation and/or reduce water loss from the basin by removal of potentially transpiring plants (Millar 1969a). However, removal of peripheral vegetation may also increase water loss by evaporation. Ideally, a certain amount of marginal wetland vegetation is needed to prevent evaporation loss and maintain optimum moisture conditions for wetland vegetation. Future research is needed to determine the specific degree of vegetative development required to optimize moisture conditions for wetland plant communities.

Working with small wetlands, Millar (1971) found that the rate of water loss per unit area varied directly with the length of shoreline and inversely with the size of individual wetlands. Water loss was principally by lateral seepage to transpiring marginal vegetation, evaporation from shoreline soil surfaces, and seepage to groundwater. He stated that during the growing season 60-80% of the shoreline water loss could be attributed to transpiration by marginal phreatophytic vegetation and evaporation from the soil surface. Shoreline-related water loss accounted for 60% or more of total water loss in wetlands .04 ha or less in size and 30-35% in wetlands greater than 1 ha.

Fluctuating water regimes also influence the concentration of dissolved solids in a wetland and may effect wetland plant community composition in some situations. Evaporation from the water surface, evapotranspiration from marginal vegetation, runoff entering a wetland, and seepage inflow all tend to increase the concentration of dissolved solids while direct precipitation on the wetland, seepage outflow, and overflow reduce the concentration of dissolved solids (Eisenlohr 1969a, Rozkowska and Rozkowski 1969, Sloan 1970). Eisenlohr (1969a) found wetlands fresher at higher elevations due predominately to the flushing effect from seepage outflow, compared to wetlands at lower elevations where dissolved solids concentrated under predominate seepage inflow effects.

An excessive amount of dissolved solids may create highly turbid water which could limit light penetration to photosynthesizing submerged vegetation thus restricting submerged plant development at certain water depths. Also, high concentrations of dissolved solids may become toxic to wetland vegetation.

A common cause of turbidity in stockponds is excessive livestock grazing which promotes greater silt loads entering the wetland basin from runoff erosion. Management practices which restrict grazing around wetland basins, encourage greater vegetative development around the pond periphery, and minimize water loss by evaporation and evapotranspiration should result in minimum dissolved solid concentrations.

Water Chemistry

Although the chemical composition of water varies from wetland to wetland, certain features are common to older strip mine ponds and artificial wetlands in the Northern Great Plains. Strip mine ponds possess unique water chemistry, a factor that could explain, in

part, differences in wetland plant composition in comparison to natural wetlands.

The chemical condition of water in strip mine ponds is a direct result of runoff from exposed materials in the surrounding spoil banks. These wetland basins act as storage or holding reservoirs for toxic pollutants carried in runoff (Crawford 1942, Riley 1954, 1960, Lewis and Peters 1955, Dinsmore 1958, Parsons 1964, Struthers 1964, Campbell and Lind 1969, Davis 1971, Coe and Schmelz 1972). A build-up of toxic pollutants in these wetland basins can limit certain nontolerant wetland plant species and decrease the diversity and value of wildlife habitat. As toxicity increases, usually on newer strip mine ponds, other normally tolerant plant species will disappear.

During the older stripping process, overburden was removed to expose the underlying coal seam. Subsoil originally on top of the coal seam was deposited on top of the spoil pile, exposed to air and precipitation. Oxidative processes after materials are exposed to air and water, convert raw materials into acids and salts which accumulate in the basin. Studying older strip mine ponds, Crawford (1942) in central Missouri, Dinsmore (1958) in Pennsylvania, Riley (1960) in Ohio, Simpson (1961) in Kansas, Struthers (1964) in Ohio, and Davis (1971) in western Maryland all reported toxic conditions for flora and fauna caused by the decomposition of marcasites, pyrites, and black amorphous pyrites (all forms of iron sulphides) into sulfates and sulfuric acid residues.

In the Northern Great Plains, acidic conditions do not appear to be a major by-product of oxidative reactions on spoil material. Most of the reported residues from oxidative processes are sulfate salts, which can also be toxic to wetland vegetation under high concentration. Sandoval et al. (1973), working with spoil bank material from various North Dakota sites, found sodium sulfate salts to be the major constituent leached from spoil material. Hinkley and Taylor (1977) and Ringen et al. (1979), working near Sheridan, Wyo., found magnesium sulfate salts to predominate in both spoil bank material and pond water. High salinity levels, as measured by specific conductance, can limit the number of plant species present. Stewart and Kantrud (1972) described a specific association of plant species for differing degrees of specific conductance. At extreme salinity levels even the most tolerant species cannot survive.

Hawkes and Anderson[3] found general alkaline conditions along with predominate sodium and magnesium sulfates in strip mine pond water throughout North Dakota, South Dakota, and Wyoming. For most wetland plant species, alkaline conditions are more favorable than acidic conditions.

Under current strict reclamation laws, strip mining operators on the Northern Great Plains must separate topsoil from subsoil, replacing each soil layer in proper perspective during reclamation activities so that revegetation can be successful. In North Dakota, state law requires mine operators to redistribute topsoil in a uniform manner after backfilling, compacting (to prevent soil erosion and leaching of toxic materials), and grading toxic subsoil.[2]

In Wyoming, topsoil and subsoil must also be segregated prior to mining and then replaced in the original sequence after mining. In addition, sources of possible water contamination within an impoundment area after reclamation must be "stablized in such a manner to prevent contamination of the impounded water" (Department of Environmental Quality 1978). Again, Montana and South Dakota have similar laws requiring separation of topsoil and subsoil prior to mining. These laws are geared towards providing environmental conditions suitable for vegetation re-establishment.

In ponds outside the Northern Great Plains, the degree of acidity present in a strip mine impoundment seems to be related to the age of the impoundment. Crawford (1942) in central Missouri, Parsons (1964) in eastern Missouri, Campbell and Lind (1969) in Missouri, and Coe and Schmelz (1972) in Spencer County, Indiana, all report considerably more acidity in younger strip mine ponds and consequently sparser wetland vegetation compared to older basins. Campbell and Lind (1969) described changes in acidity on Missouri ponds as a successional trend characterized by decreasing acidity (as indicated by increasing pH values) and increasing biological productivity, both for flora and fauna, with increasing basin age. They believe that weathering spoil piles release reduced quantities of sulfuric acid and total dissolved solids into the basin, allowing an increase in bicarbonate alkalinity concentration (which acts as a buffer in acidic conditions) and thereby creating alkaline conditions in aging ponds.

Increasing alkalinity creates more favorable conditions for the establishment of wetland plants ordinarily intolerant to acidic conditions. As alkalinity conditions increase, a greater diversity of wetland vegetation appears, to a point, improving wildlife habitat quality.

Generally, resource managers can do little to alleviate acidic conditions in new strip mine ponds without large expense and time involved. Also, any treatments would have to be a continued process over a long period until the leachate was nontoxic.

Crawford (1942) suggests neutralizing acidic conditions in central Missouri strip mine ponds by adding powdered limestone, marl, soda ash, caustic soda, or potash. However, such a process is expensive, time consuming, and requires a disposal area for the precipitated calcium sulfate sludge, which can be 20-40% of the treated water volume. Also, any new precipitation would leach additional salts and acids into the basin from surrounding spoils and destroy previous treatments.

More detailed information on specific chemical parameters effecting wetland vegetation was described by several investigators working on strip mine ponds outside the Northern Great Plains. Crawford (1942) in

[3]*Hawkes, C. L., and M. T. Anderson. Physical and chemical features of strip mine ponds in the Northern Great Plains. I. Coal strip mine ponds. (Unpublished report at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

central Missouri, Burner and Leist (1953) in Kansas, Riley (1954) in Ohio, Lewis and Peters (1955) in southern Illinois, Bell (1956) in southern Illinois, Davis (1971) in western Maryland, and Coe and Schmelz (1972) in Indiana found water pH to be in the range from high acidity (pH 3.0), especially on younger ponds, to slightly basic (pH 8.2). In moderate acidic conditions only *Typha* species prevail, but as acidity decreases and alkalinity increases a wider variety of plant species can prosper. Under highly acidic conditions, pH of 4.0 and below, no species can survive. Generally, water pH of 7.0 and greater are required for adequate wetland vegetation establishment (Crawford 1942, Coe and Schmelz 1972).

Hawkes and Anderson,[3] working on strip mine ponds in North Dakota, South Dakota, and Wyoming from 1976 to 1978, found pH values ranging from 7.7 to 9.9. Generally higher alkaline conditions in ponds on the Northern Great Plains were not considered to be problematic for wetland vegetation on those ecosystems.

Burner and Leist (1953) in Kansas, and Davis (1971) in western Maryland, found identical pH values at the surface and bottom in their study ponds. In a southern Illinois study, Bell (1956) reported a noticeable decrease in the density of wetland vegetation at pH 6.6 with only emergent plant species present at pH values lower than 6.4.

Lewis and Peters (1955) in southern Illinois, Davis (1971) in western Maryland, and Coe and Schmelz (1972) in Indiana all reported high specific conductance values caused by high concentrations of dissolved salts. Specific plant species have been known to be associated with varying degrees of specific conductance of surface water (Stewart and Kantrud 1972).

Lewis and Peters (1955) found considerably lower specific conductance in surrounding farm ponds as compared with coal strip mine ponds. Davis (1971) reported slightly higher specific conductance at the bottom of Maryland strip mine ponds in comparison to surface readings. Values were highest during July, August, and September, the peak maturation period for wetland vegetation.

Hawkes and Anderson,[3] on the Northern Great Plains, found low salinity (as measured by total filterable residue) levels in coal strip mine ponds. Specific conductance on these impoundments during 1976-78 ranged from 500 to 5959 μmhos/cm. Hammer (1978), working on 60 lakes in the prairies of southern Saskatchewan, reported a range of specific conductance of 3,000-28,000 μmhos/cm.

Sulfate was the predominate anion in Kansas, Ohio, and Missouri strip mine ponds from the oxidation of toxic spoil materials and subsequent runoff (Simpson 1961, Struthers 1964, and Campbell and Lind 1969). Hawkes and Anderson[3] found similarly high levels of sulfate in 20 Northern Great Plains coal strip mine ponds with a range of 292-4894 mg/1. Rockett (1976) and Wangness (1977), both studying coal strip mine ponds near Sheridan, Wyo., also reported sulfate as the predominate anion in that region. Hammer (1978) reported sulfate as being the major anion in 53 of 60 prairie lakes he studied in southern Saskatchewan. In western Maryland, Davis (1971) found no significant difference in sulfate concentration between surface and bottom areas of his study ponds. Sulfate concentrations, in the form of sulfate salts, can be especially inhibitory to wetland vegetation at high concentration levels.

Crawford (1942) and Hawkes and Anderson[3] were the only investigators to report detailed information on the concentration of other mineral substances such as sodium, potassium, iron, manganese, calcium, chloride, and magnesium. However, Simpson (1961) and Campbell and Lind (1969) reported that calcium, magnesium, and iron were the dominate cations in Kansas and Missouri strip mine ponds.

Crawford (1942), working on Missouri strip mine ponds, stated that the concentration of all mineral substances followed seasonal changes. Of all minerals, calcium displayed the highest concentration in extremely polluted and acidic ponds. Magnesium concentrations were irregularly distributed in five Missouri ponds studied by Crawford (1942). Sodium occurred in smaller concentrations than either calcium or magnesium in all five study ponds. Potassium and iron concentrations were highest in the most acidic ponds. Finally, manganese concentrations were inversely correlated with hydrogen ion levels.

At excessive concentrations, any one of the mineral substances can become toxic to wetland flora. At this point, not enough information is known about manipulating environmental factors to control concentrations of mineral substances that may be toxic to wetland vegetation. Again, more research is needed on constructed impoundments to answer these questions.

Hawkes and Anderson[3] reported that the major cations on 20 coal strip mine ponds they studied on the Northern Great Plains were sodium and magnesium with concentration ranges of 5-365 and 32-1339 mg/l, respectively. Other concentrations of cations and anions that they reported were calcium 14-314 mg/l, potassium 11-48 mg/l, and chloride 3-49 mg/l. They commented that the major cations and anions present in their study ponds were directly related to the chemical composition of the surrounding mine spoil material. The expression of wetland vegetation development is likewise related to the chemical composition of pond water.

Among the organic macronutrients measured by Hawkes and Anderson,[3] total Kjeldahl nitrogen was highest in concentration with a range of 0.15-1.94 mg/l for all 20 ponds investigated. Total phosphorus and nitrate were represented by concentration ranges of 0-0.53 and 0-0.86 mg/l, respectively. These organic nutrients are probably the most important for plant growth and development. Drawdowns enhance presence of these macronutrients by allowing a more rapid decomposition of residual material in presence of aerobic bacteria.

Other miscellaneous chemicals and heavy metals reported by Hawkes and Anderson[3] for 20 Northern Great Plains coal strip mine ponds, with ranges of concentration (in mg/l), were aluminum 0-660, arsenic 1-4, cadmium 3-50, chromium 0-10, copper 1-22, iron

10-1100, lead 27-490, manganese 0-130, mercury 0-0.1, selenium 0-16, silica 100-19,000, and zinc 10-70.

Various theories on dissolved oxygen concentrations in strip mine ponds were reported by several workers. Simpson (1961) found that the concentration of dissolved oxygen in Kansas ponds was inversely related to water temperature and directly related to pH and photosynthetic rate of submerged plants. Tobaben (1969) and Coe and Schmelz (1972) reported lower oxygen concentration in young, highly acidic ponds; this was caused by the oxidation of dissolved sulfur or ferrous compounds. Coe and Schmelz (1972) stated that dissolved oxygen increases as oxidizable materials decrease and the density of phytoplankton and higher aquatic plants increases.

Dissolved oxygen concentration is important for respiratory processes in submerged vegetation and for emergents during winter when ice forms over the root crowns of shallowly submerged emergents. In cases where highly turbid water restricts light penetration and resulting photosynthetic processes, dissolved oxygen concentrations may become dangerously low from respiring flora and fauna without compensating photosynthetic production of oxygen. Resource managers may want to consider installing aerators on constructed impoundments over winter months to maintain dissolved oxygen concentrations.

In a western Maryland study, Davis (1971) reported that dissolved oxygen varies with depth and month. Burner and Leist (1953) found the lowest oxygen concentration in July and at the pond bottom on Kansas ponds. However, Lewis and Peters (1955) reported higher oxygen concentations at the bottom of southern Illinois ponds because extreme water clarity allows light penetration and corresponding rapid photosynthetic rates in submerged aquatic plants attached to the pond bottom.

Bell (1956) attributed high oxygen concentrations in both the epilimnion and hypolimnion of southern Illinois ponds to infertile water with a low biochemical demand for oxygen. He stated that high dissolved oxygen concentrations permitted *Typha* species to invade areas with water depths up to 60 cm. Sifton (1959) found that low oxygen concentrations are ideal for germination of *Typha latifolia* propagules; but once growth ensues, higher oxygen concentrations are required to meet increasing respiration rates. Linde et al. (1976) reported that *Typha* initially germinates in shallow water near shore and spreads to deeper water by vegetative propagation.

Crawford (1942) indicated that dissolved oxygen concentrations in central Missouri ponds are inversely related to the amount of organic matter on the pond bottom. Heavy decomposition of organic matter residue by anaerobic bacteria results in consumption and corresponding decrease in oxygen concentration and an increase in dissolved carbon dioxide (Burner and Leist 1953).

Hawkes (1978) reported that dissolved oxygen in Northern Great Plains coal strip mine ponds was near saturation and optimum for wetland vegetation due to wind action on water. Dissolved oxygen in 20 ponds he studied ranged from 5.9-20 mg/l with a mean of 9.3.

Crawford (1942) classified Missouri strip mine ponds into three types based on dissolved oxygen concentration. Oligotrophic ponds are rich in oxygen concentration at all levels with little deposition of organic matter and slow decomposition rates. Eutrophic ponds have low dissolved oxygen concentrations on the bottom, an abundance of dissolved nitrogenous substances, and rapid rates of decomposition with correspondingly high dissolved oxygen demand. Dystrophic ponds, characteristic of peat bogs, display extreme concentrations of nitrogenous compounds and organic acids. Oligotrophic ponds represent the best environmental conditions for wetland vegetation with respect to dissolved oxygen concentrations.

Water color and clarity in strip mine ponds has been discussed by several investigators. Tobaben (1969) reported alkaline lakes in Kansas to be greenish in color and acidic lakes blue-green in color due to the precipitation of colored organic matter. Crawford (1942) and Campbell and Lind (1969) found Missouri strip mine ponds deep reddish brown due to forms of dissolved iron. Parsons (1964) attributed turbidity of many strip mine ponds in Missouri to soluble ferric oxide concentrations. Bell (1956) concluded that in Illinois strip mine ponds ferric oxide acts as a filtering agent upon precipitation from basin water. Flocculation of negatively charged suspended soil particles with positively charged ions (sodium, potassium, calcium, and magnesium) results in a precipitate which settles to the bottom and promotes water clarity. Crawford (1942) stated that water clarity in the strip mine ponds he studied was due to the precipitate that forms when sulfuric acid flocculates with suspended materials.

Excessive water color can become a limiting factor for wetland plant establishment when light penetration and resulting photosynthesis is effected. However, in most cases light penetration is limited more by suspended solids rather than dissolved minerals. Precipitates formed by flocculation of suspended materials with oppositely charged ions can effect submerged vegetation by coating leaf surfaces and restricting photosynthesis. This can be an especially serious problem in deeper water where wave action is not present to remove precipitate material from submerged leaves (Emerson 1961).

The only information available on the water chemistry of stockdams comes from Hawkes and Anderson,[4] investigating nine livestock watering ponds on the Northern Great Plains. They found generally alkaline conditions in livestock watering ponds with pH values ranging from 6.8 to 10.3 . Specific conductance, a measure directly related to total filterable residues, was generally low with a range of 177-3100 umhos/cm. Salinities were not considered to be high enough to

[4]*Hawkes, C. L., and M. T. Anderson. Physical and chemical features of selected livestock ponds in the Northern Great Plains. (Unpublished manuscript at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)*

limit productivity on Northern Great Plains livestock watering ponds. Generally, these chemical parameters were well within acceptable levels for wetland plant development.

Among cations and anions, sulfate represented the highest concentrations followed by sodium with ranges of 28-924 and 8-602 mg/l, respectively. Other parameters were calcium 19-136 mg/l, magnesium 10-60 mg/l, potassium 10-23 mg/l, and chloride 2-19 mg/l.

Concentrations of organic macronutrients were high because of the large amount of aquatic vegetation associated with these livestock ponds. Total Kjeldahl nitrogen displayed the highest concentration, followed by total phosphorus and nitrate, with ranges of 0.27-2.63, 0.01-1.59, and 0-2.14 mg/l, respectively. Other miscellaneous chemicals and heavy metals reported by Hawkes and Anderson[4] for nine Northern Great Plains livestock ponds, with ranges of concentration (in mg/l), were aluminum 0-110, arsenic 1-13, cadmium 2-28, chromium 0-10, copper 1-9, iron 10-120, lead 22-350, manganese 0-3000, mercury 0-0.2, selenium 1-2, silica 400-14,000, and zinc 10-30.

Lathwell et al. (1969), working with artificial wildlife marshes in New York, reported trends in pH, carbonates, and dissolved oxygen. They found pH relatively stable diurnally and seasonally with values ranging from 8 to 10, well within acceptable pH range for the establishment of a variety of wetland vegetative types. Total alkalinity concentrations, a component of the carbonate system which provides a buffering effect under high acidity, influences toxic levels of dissolved heavy metals and the resulting wetland plant community composition. They noted that as alkalinity declined, heavy metal concentrations approached toxic levels for flora and fauna. Dissolved oxygen concentrations fluctuated substantially each day of the growing season. Lowest concentrations were observed in early morning hours when photosynthesis of aquatic plants was reduced.

As in strip mine ponds, chemical composition of water in natural wetlands is governed in part by the nature of the surrounding watershed (Moyle and Hotchkiss 1945, McCombie and Wile 1971). The extremely dynamic fluctuation of water levels in natural wetlands, caused mainly by evaporative loss and evapotranspiration during summer and spring runoff, is a major factor effecting the concentration of dissolved substances (Moyle 1945, Kadlec 1962, Rozkowska and Rozkowski 1969, Sloan 1970, Daborn 1976). Concentrations of dissolved substances are higher in low water levels typical at the end of the growing season and lower in higher water levels of early spring. In extremely dry summers, concentrations of dissolved substances may approach toxic levels for wetland vegetation in August and September. If possible, managers should consider adding water to wetland basins by midsummer if water regulation is available.

Moyle (1945) noted that presence of a white-powdered ring along shorelines or on mudflats indicates high salt content. Usually, wetlands with high salt content will support vegetation of high salt tolerance such as saltgrass (*Distichlis stricta*). As with strip mine ponds, the major cations in natural wetlands and lakes are calcium, magnesium, sodium, and potassium (Moyle 1945, Moyle and Hotchkiss 1945, Stewart and Kantrud 1972).

A characteristic of natural wetlands not found in strip mine ponds is the large amount of dead organic matter produced primarily from aquatic vegetation. Dineen (1953), Wilson (1958), Emerson (1961), Kadlec (1962), and Walker and Wehrhahn (1971) mention extremely low concentrations of dissolved oxygen and high carbon dioxide levels in basins with large amounts of organic matter. Rapid bacterial decomposition in warm, shallow water (utilizing large amounts of dissolved oxygen and producing high levels of carbon dioxide) overshadows the photosynthetic production of oxygen by aquatic plants. In restricted, shallow areas excessive oxygen consumption by bacterial decomposition could limit the amount of oxygen available for respiration by submerged vegetation, and result in a decrease of potential waterfowl food material.

Walker and Wehrhahn (1971) reported high levels of hydrogen sulfide in basins with high organic matter residue. Another characteristic of basins with high organic residue is the brownish water color from decomposition processes compared to greenish or blue-green color in strip mine ponds (Dineen 1953).

Water Temperature and Light Penetration

According to various workers, water temperature regimes were quite variable among strip mine ponds and natural wetlands. Crawford (1942), in central Missouri, reported that the highly acidic strip mine ponds he studied were not thermally stratified but stratification did occur in his eutrophic "control" ponds. Tobaben (1969) found only two of six study ponds in Pittsburgh, Kan., thermally stratified. Acidic ponds in his study area remained homothermous throughout the study period, which he attributed to high water clarity and a greater rate of thermal conductivity compared to alkaline ponds.

The effects of water temperature and thermal stratification on wetland vegetation are not known. Water temperature, however, is known to influence the time of germination in spring. Again, more research is needed to better understand the ecological relationship.

Lewis and Peters (1955) and Davis (1971) noted that their study ponds were thermally stratified, especially during June through October, with an abundance of oxygen in the lower thermocline and hypolimnion due to heavy plant growth on the pond bottom. Exceptional water clarity permitted good light penetration to photosynthesizing submerged vegetation. Burner and Leist (1953) and Simpson (1961) found no evidence of thermal stratification in their study ponds although changes in air temperature slightly effected surface water temperature. Parsons (1964) reported summer thermal stratification in reddish-black colored strip mine ponds; the stratification is caused by ferric iron oxides. Parsons (1964) encountered homothermous conditions in blue-colored ponds.

According to Crawford (1942), thermal stratification in strip mine ponds is caused by a combination of depth, wind, isolation, and turbidity. Campbell and Lind (1969) reported that seasonal water temperature reaches its maximum by July with the greatest rate of heat absorption in spring. Spring heat absorption triggers germination in aquatic plants.

Hawkes and Anderson,[4] studying nine livestock watering ponds on the Northern Great Plains, reported the absence of thermal stratification "due probably to shallow depths (maximum depth ranging between 1.7 and 6.0 m) and the relatively constant prairie winds occurring in the region". Water temperatures on their study ponds ranged from 2 to 27° C. Germination of wetland vegetation on shallow livestock ponds probably occurs earlier than deeper strip mine ponds due to more rapid warming.

Much variation has been reported in water temperature regimes on natural wetlands. In New York and Sasketchewan respectively, Emerson (1961) and Walker and Wehrhahn (1971) reported thermal stratification in natural wetlands with much colder temperatures in bottom water layers. Walker and Wehrhahn (1971) hypothesize that in many Sasketchewan wetlands there is continual upwelling of cold groundwater entering the wetland basin. Colder temperatures in bottom water layers may be beneficial to submerged vegetation since a higher level of dissolved oxygen generally occurs in colder waters. However, germination in spring could be delayed in comparison to warmer waters of shallow areas.

Dineen (1953) and Wilson (1958), both in Minnesota, and Daborn (1976), in western Canada, concluded that there was no thermal stratification in the shallow-water basins they studied. Smaller water volumes, characteristic of natural wetlands, result in a lower heat storage capacity and a rapid response of water temperature to fluctuating air temperatures (Daborn 1976).

Light penetration is another factor that effects aquatic plant growth by regulating photosynthesis and corresponding production of aquatic vegetation. Campbell and Lind (1969) found penetration to be greatest in slightly acid strip mine ponds but reduced in highly acidic and alkaline ponds, another possible explanation for reduced submergent vegetation on highly acidic strip mine ponds. In Kansas, Burner and Leist (1953) reported Secchi disc readings ranging from 60-225 cm in strip mine ponds. The depth of light penetration and resulting production of submergents corresponds directly to the concentration of dissolved solids (Beeton 1958, Emerson 1961, Coe and Schmelz 1972).

Hawkes (1978) reported secchi disc values of coal strip mine ponds on the Northern Great Plains to range from 0.4 to 4.4 m with a mean of 1.7, while livestock watering ponds ranged from 0.3 to 2 m with a mean of 0.8. He contends that the low secchi disc readings, indicating large concentrations of suspended particulate materials, may suggest lower production of phytoplankton and rooted aquatic vegetation caused by inhibited photosynthesis from reduced light penetration in the water column.

Death of aquatic plants, caused by precipitation of solids restricting light intensity on photosynthesizing leaves, is another complication associated with high concentrations of dissolved solids (Emerson 1961). Although not specifically mentioned by other authors, algal blooms may also contribute to lower aquatic vegetation production by restricting light penetration to photosynthesizing submerged plants and in some cases, excessive oxygen consumption for respiratory processes.

Soil Chemistry

Not much information is available on the soil chemistry of strip mine ponds. However, several investigators provide physical descriptions of both spoil pile material and submerged soil. In Ohio, Riley (1960) found the composition of surrounding spoil material to be 10% sand, sandy shale, and sandstone; 42% silty shales and loams; and 48% clay and limestone. He calculated that 4% of the spoil material was toxic to plant and animal life, 7% marginally toxic, 47% acidic but not necessarily toxic, and 42% calcareous. Bell (1956) found Illinois strip mine ponds to be primarily composed of calcareous shales. Parsons (1964) reported that 78% of spoil material in Missouri strip mine ponds was toxic to flora and fauna and pH values were commonly less than 4.0, seriously inhibiting vegetative development. Riley (1954) reported considerable variation in the pH of spoil material in Ohio. The common range was 4.5-6.5.

Bell (1956) and Brewer and Triner (1956) found Illinois spoil materials to be low in organic matter and nitrogen, a major nutrient for growing vegetation, but rich in potassium, phosphorus, and potash. Unlike other workers, Tobaben (1969) reported Kansas spoil piles to be well-vegetated with compacted soils and little erosion. He found that calcium was directly correlated with pH values.

Packer (1974) reported that soils west of the Missouri River in western North Dakota, eastern Montana, and Wyoming were deficient in phosphorus while soils in eastern North Dakota were deficient in nitrogen. In addition, sodium-toxicity problems are common in North Dakota spoil material because of the large amount of sodium associated with overburden of lignite coal beds. Sub-bituminous coal beds in eastern Montana and Wyoming have substantially less sodium concentrations and therefore no sodium-toxicity problems with respect to vegetative development.

Packer (1974) characterized spoil bank material in the Northern Great Plains as being "nearly always alkaline." Most spoil material in this region has a high saturation of clay and cation composition, which explains the high salinity levels found in most subsoils. Packer (1974) added that salinity problems can be corrected by introducing gypsum to subsoil material. However, this process is expensive.

In some areas of the Northern Great Plains, wind and water erosion of spoil bank material is a serious problem because of sandy soils which lack silt and clay for the formation of large aggregates. Some of the most highly erodible spoil material is found in North Dakota where sodium in clays and sandy soil predominate (Packer 1974). Constantly shifting spoil material from erosion processes hinders plant establishment, especially near shoreline where erodable materials enters the wetland basin.

Less is known about the submerged soils of strip mine ponds. Crawford (1942) described basin floors in Missouri, as a combination of gravel, shale, coal and sand mixed with dead vegetation. Closer to shore, Crawford (1942) found a shelf of soft, gray muck formed by flocculation of silty spoil material in the acidic pond water. Moyle and Hotchkiss (1945) reported that soft, mucky bottoms were unfavorable for many aquatic plants in Minnesota lakes. Riley (1960) found basin bottoms to vary from clays to clay, silty, or sandy shales; sandstones, and limestones.

There is no specific information available on soil characteristics for stockdams. However, Jupp and Spence (1977), working on Scottish lakes, in contrast to the findings of Moyle and Hotchkiss (1945) working in Minnesota, reported that vegetative growth is greater on fine-particle mud and clay bottoms than on coarse, gravelly bottoms. They concluded that fine-particle mud and clay bottoms, usually deposited in wind-sheltered areas, contain more nutrients than coarse-particle bottoms subjected to wind and subsequent wave action. Consequently, sheltered areas support more vegetative growth because of a higher nutrient status. Wilson (1937) stated that in Wisconsin lakes 88% of the plant biomass was found on organic soils, 22% on sand and silt bottoms, and no aquatic plants on pure gravel bottoms.

Resource managers, when anticipating construction of new impoundments, should consider wind-sheltered areas to reduce the erodibility of substrate from wave action. Wildlife, particularly waterfowl, also prefer wind-sheltered areas where an abundance of cover and food materials prevail.

Chemical features of natural wetland soils closely parallel soils of artificial wetlands, but some differences are apparent. Walker and Wehrhahn (1971) reported a thick layer of muck covering surface soils of Sasketchewan wetlands which results from large amounts of organic matter present on natural wetlands. This organic matter offers sufficient nutrients for plant growth as typified by generally greater vegetative development on natural wetlands.

Emerson (1961) highlighted the significant chemical features found in New York marshes. He recorded higher pH values in submerged soils because of ferrous, manganous, and ammonium hydroxides produced from anaerobic reducing conditions. The magnitude of total alkalinity, reflecting limestone content of the substrate and expressed as calcium carbonate, was directly correlated with the magnitude of nutrients essential for plant growth. Emerson (1961) concluded that alkalinity can act as an indicator of soil fertility. With regard to calcium, he found a direct correlation between soil calcium levels and pH. This is similar to the findings of Tobaben (1969) on Kansas spoil material.

Nitrogen, an essential element in plant growth, was found as the ammonium ion in submerged soil (converted by anaerobic bacteria) because conversion to nitrite and nitrate by aerobic bacteria cannot occur (Emerson 1961). However, when the soil dried, as on an exposed mudflat after drawdown, regular microbial nitrification processes proceeded under aerobic conditions and increased the availability of nitrogen for plant utilization (Emerson 1961, Kadlec 1962).

Harter (1966) stated that the main problems associated with nitrification processes in wet soils is the inhibition of aerobic bacterial action caused by the deficiency of oxygen. The amount of oxygen in soil is inversely proportional to water content. As soils change from dry, well-aerated to waterlogged conditions and vice versa, many bacterial decomposition processes are altered.

In many cases, the relationship between wetland vegetation and environmental factors on constructed impoundments is not known simply because of a lack of research information. The affects of environmental factors on the expression of wetland plant community development on constructed impoundments must first be understood before resource managers can devise management plans for these recently recognized ecosystems.

The need for additional ecological research on constructed impoundments is sufficiently warranted as demonstrated by our lack of information. Until more information is gathered, resource managers must extrapolate information from natural wetland studies to formulate management plans for these unique ecosystems.

Vegetation-Environmental Relationships

Specific floristic compositions have not been described for strip mine ponds or stockdams. However, general trends of vegetation development were indicated by some workers for strip mine ponds, stockdams, and natural wetlands.

Crawford (1942) found only a few species of aquatic plants distributed over Missouri strip mine ponds and no species in the most highly acidic ponds. He noted that more species occurred as water alkalinity increased. *Typha* species were the most common invaders. Crawford (1942) theorized that acidity and siltation are the main factors controlling biological processes in Missouri strip mine ponds. As acidity decreases and siltation increases, the diversity of organisms capable of existing increases, eventually modifying the habitat so conditions for plant invasion and establishment become more favorable. Riley (1960) reported that *Typha angustifolia*, *Typha latifolia*, and *Sagittaria cuneata* were the most abundant species of

vascular plants in Ohio strip mine ponds. Lewis and Peters (1955) and Bell (1956) found that the two earliest invaders and most productive species in new strip mine ponds in Illinois were *Typha latifolia* and *Potamogeton foliosus* (fig. 4).

Hawkes (1978) and Olson (1979) indicated that water turbidity and near-shore basin slope were major factors influencing biological processes in the Northern Great Plains. Highly turbid water, caused by suspended particulate material, limits light penetration and associated photosynthetic activity in aquatic vegetation. This is reflected in lower plant productivity and lower invertebrate populations depending upon aquatic vegetation for existence. Likewise, steep, near-shore basin slope limits the area favorable for aquatic plant community expansion and subsequently limits the total biological productivity of that community. Acidity does not appear to be a major problem effecting biological productivity in Northern Great Plains coal strip mine ponds since spoil material is generally alkaline in nature (Packer 1974, Hawkes 1978).

Walker and Wehrhahn (1971) commented on the complexity and variation in wetland vegetation occupying the glaciated prairie potholes. Auclair et al. (1973) discussed the mosaic pattern of nearly monospecific aquatic communities characteristic of natural wetlands. There is a strong tendency among emergent dominants to exclude each other.

Recently, considerable work has evolved around correlation of the distribution of aquatic macrophytes with environmental factors. A number of major environmental factors have been utilized to explain wetland plant distribution in strip mine ponds, artificial wetlands, lakes, and natural wetlands.

Crawford (1942), Burner and Leist (1953), Davis (1971), and Coe and Schmelz (1972) singled out basin slope as a major factor that effected plant distribution in strip mine ponds. They contend that the almost vertical position of the surrounding shoreline provides few shallow areas for production of aquatic vegetation and fish. Crawford (1942) and Coe and Schmelz (1972), adding water pH as another major factor, stated that steep shores, limited shoal areas, and high water acidity discourage invasion by aquatic plants. They concluded that shallow lakes are more productive because of enhanced exposure to light and air. Lewis and Peters (1955) and Bell (1956) found that fluctuating water levels and water pH were the major factors affecting plant distribution in Illinois strip mine ponds. They found that water level fluctuations beyond 1 m were not tolerated by *Typha* species. Riley (1960) stressed that flora density in Ohio, was determined by a complex set of factors including basin age, slope, water depth, water pH, soil fertility, and soil pH.

There is little information available which deals strictly with environmental-aquatic plant distribution relationships in stockdams. However, a few authors provided information for manipulation of aquatic vegetation to enhance waterfowl production in livestock watering ponds.

Several authors reported that waterfowl productivity increased when wetland vegetation was subjected to light or no grazing by domestic livestock. More attractive nesting and brood rearing cover was created

Figure 4.—Species of *Typha* are the earliest invaders of newly formed strip mine ponds and one of the most productive.

under restricted grazing. Berg (1956) found, in eastern Montana, that plant density, average plant height, and plant diversity increased in wetland plant communities fenced from grazing livestock. As a result, waterfowl nesting densities and brood production increased within fenced areas, especially on the larger reservoirs. Lokemoen (1973) reported that in western North Dakota, reduced grazing pressure improved waterfowl habitat through enhanced wetland plant development. Breeding pairs were significantly more numerous on lightly grazed ponds with grassy shorelines while broods were more numerous on ponds with brushy shorelines of emergent vegetation.

Evans and Kerbs (1977) reported that, in western South Dakota, rapidly changing water levels, light livestock grazing pressure, and gently sloping shorelines encouraged greater waterfowl nesting and brood use on stockdams through the enhancement of wetland plant communities. They noted that grazing had a considerable impact on the wetland vegetation around stockdams. In a similar study in south central South Dakota, Rumble (1979) found that excessive grazing of shoreline vegetation reduced the number of waterfowl broods using a pond. He concluded that excessive grazing and trampling of wetland vegetation increased pond turbidity and reduced biological productivity.

Dane (1959) and Lathwell et al. (1969), working with artificial wetlands in New York, indicated that basin slope is an important factor in plant distribution. Lathwell et al. (1969) stated that greater plant growth occurred in shallow basins, but indicated that specific factors controlling production in wetlands were not known. Dane (1959) reported that species composition of wetland plant communities was governed by basin slope, nature of the bottom soils, water clarity, depth, and extent of water level fluctuation. He concluded that the more gently sloping basins were characterized by wider zones of wetland vegetation (fig. 5).

Moyle (1945, 1956), Moyle and Hotchkiss (1945), Sculthorpe (1967), and Modlin (1970) indicated that plant distribution in lakes is dependent on water quality, bottom soil texture, and bottom soil fertility. Another major factor that often effected plant density was the amount of light penetration reaching submerged aquatics. As water depth and turbidity increase, the amount and depth of light penetration decreases (Juday 1934, Robel 1961, Spence and Chrystal 1970). Spence and Chrystal (1970) concluded that light penetration is as important as substrate factors or intraspecific competition in influencing plant establishment. Natelson (1954) and Swindale and Curtis (1957), working with submergents found water chemistry, depth, and substrate fertility important in Wisconsin lakes. Jupp and Spence (1977) reported that *Potamogeton filiformis* and *Potamogeton pectinatus* were limited by wave action and waterfowl grazing. They claimed that waves reduced plant biomass directly in exposed areas and indirectly by creating coarse, nutrient-poor bottom soils.

Features of the bottom substrate were often discussed as factors that effected plant establishment. Pearsall (1926), Wilson (1937), and Misra (1938) mentioned substrate fertility as the prime factor determining establishment. In a California study, Mall (1969)

Figure 5.—Natural wetlands and stockdams with gently sloping basins, pronounced water-level fluctuations, and average water pH display wider, more developed zones of wetland vegetation.

concluded that the length of soil submergence is most important, followed by levels of soil salinity. Veatch (1932) discovered the most prolific growth of aquatic plants on soft, slimy, sedimentary peat or organic mud bottoms and reduced growth on nearly pure sand, cobbles, or hard rock in Michigan. Water level fluctuations were also mentioned as prime factors (Graham and Henry 1933, Potzger and Van Engel 1942, Mandossian and McIntosh 1960). Potzger and Van Engel (1942) included physical factors of the substrate (soil texture, wave action causing coarse soils, and slope) as factors that effected plant establishment. Mandossian and McIntosh (1960) and van der Valk and Bliss (1971) discussed chemical characteristics of the water in addition to fluctuating water levels. Zutshi (1975) stated that prolific growth of aquatic plants was associated with shallow water, rich organic soils, and little wave action.

Many investigators working with natural wetlands have found that water depth and permanence influences the establishment of wetland plant communities (Kadlec 1962, Harter 1966, Millar 1969a, Smith 1969, Auclair et al. 1973). Studying in North Dakota, Stewart and Kantrud (1972) found a definite association of specific plant species with differing water permanence (not depth) and specific conductance of surface waters. Walker and Coupland (1968), Walker and Wehrhahn (1971), and Dirschl and Coupland (1972) reported that disturbance, soil fertility, water regime, and salinity account for the bulk of variation in the characteristics of plant communities in Canadian wetlands. Emerson (1961) divided the major factors influencing plant establishment into chemical features (soil pH, soil fertility) and physical features (slope, water depth, hardness of the bottom). He reported that wetlands with steep slopes had narrow emergent zones with sparse vegetation development. Auclair et al. (1976a, 1976b) believed that soil fertility was the sole factor in plant establishment and growth.

Several workers have reported on the practical aspect of fluctuating water levels and deliberately manipulated levels for selecting and managing specific plant communites (Schmidt 1951, Johnsgard 1956, Kadlec 1962, Robel 1962, Harris and Marshall 1963, Anderson and Glover 1967, Burgess 1969, Meeks 1969). Drawdowns provide several advantages for wetland plant communities. They (1) allow a greater rate of organic matter decomposition under aerobic conditions with a subsequent release of nutrients into the mudflat, (2) favor germination of aquatic plant seeds and subsequent development of lush emergent cover, and (3) enhance the availability of aquatic plant seeds to feeding waterfowl (Kadlec 1962). Interspecific competition, soil chemical characteristics, the rate at which soils dry after drawdown, water depth after flooding, and seed availability all interact to influence which aquatic plants will invade an exposed mudflat (Meeks 1969).

Pond age, another variable which could effect the development of wetland plant communities in strip mine ponds, was found to be insignificant in Illinois ponds (Lewis and Peters 1955). They concluded that the nature of spoil material is more important than age in determining chemical characteristics of pond water and eventual establishment of aquatic plants.

In the Northern Great Plains, the influence of pond age on wetland plant establishment and development is still unknown (Hawkes 1978 Olson 1979). It has been suggested that the chemical moderation of spoil bank material over time, a corollary process associated with age, is more important than pond age in influencing wetland plant development.

Summary

As strip mining and stockdam construction accelerate in the Northern Great Plains, resource managers must develop more intensive management plans for these specialized ecosystems. As indicated by the current literature, there is little ecological information available, and only limited future research interest exists for these rangeland ecosystems. More information is needed on the ecology and biology of both flora and fauna of these ecosystems.

We must realize the additional potential assets offered by managing wetland vegetation on these rangeland impoundments. With proper management, we can convert these ecosystems into functional multiple use areas.

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Water regime, chemical features, temperature factors, light penetration, substrate properties, and physical characteristics are described for Northern Great Plains strip mine ponds and stockdams, followed by a discussion of how their interaction determines wetland plant community composition and resulting wildlife habitat quality for consumptive and non-consumptive resource utilization.

Keywords: Strip mine ponds, stockdams, wetland management, wetland wildlife habitat, wetland vegetation ecosystems

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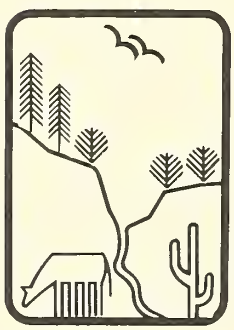

Southwest

Great Plains

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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